Supersonic Particle Deposition Technology for Repair of Magnesium Aircraft Components

New FY2006 ESTCP Project

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Standard Form 298 (Rev. 8-98)
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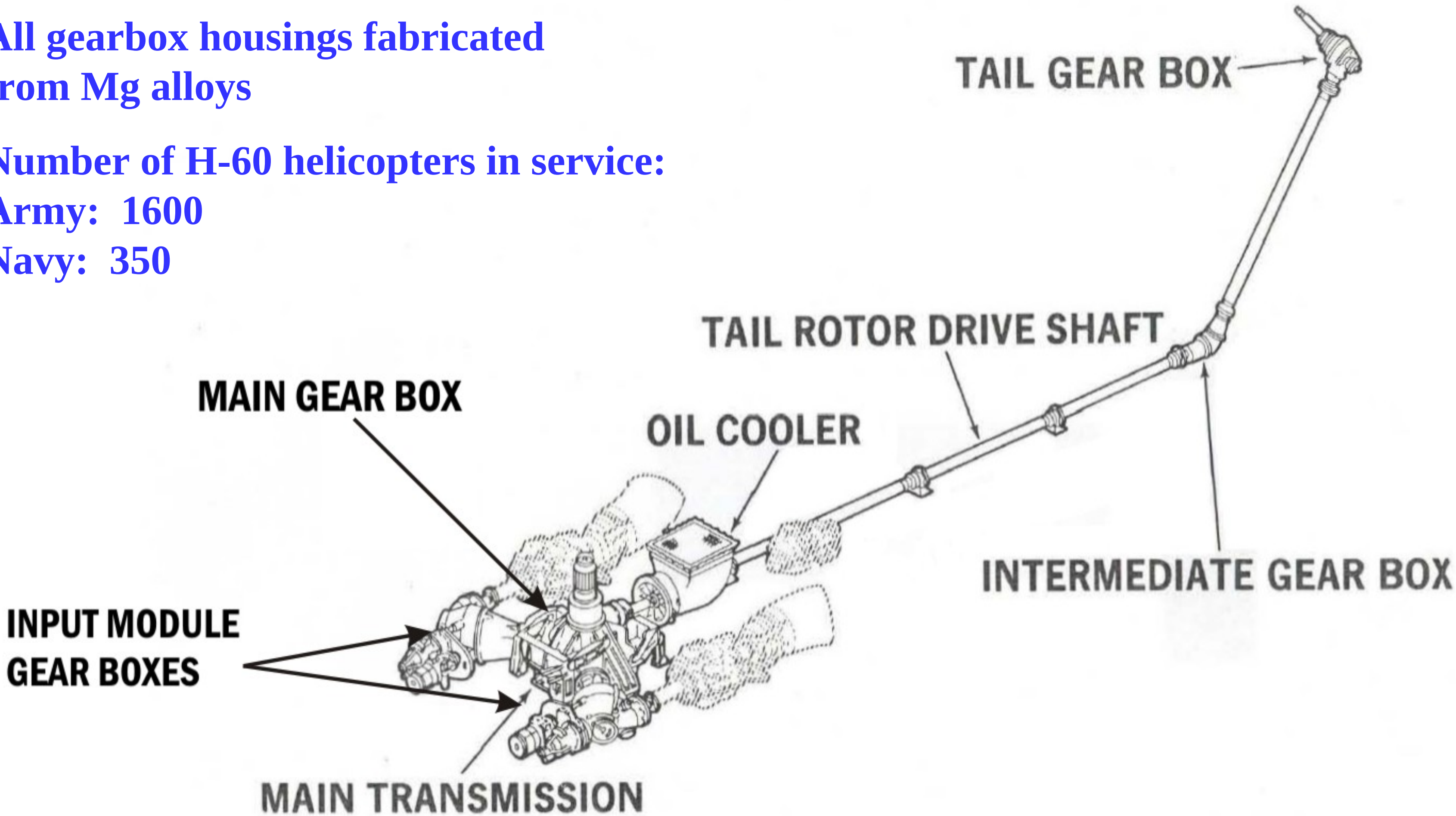
Use of Magnesium Alloys

- ***Magnesium alloys used throughout the aircraft industry for applications such as gearboxes on helicopter transmissions and gas turbine engines***
- ***Use of magnesium alloys expected to increase due to favorable properties:***
  - ***40% lighter than steel and 20% lighter than aluminum on a like-for-like strength ratio***
  - ***Good damping qualities, absorbing noise and vibration***
  - ***Low density means easier, faster machining of components***
  - ***High thermal conductivity and good EMI shielding***
  - ***Ductile, with ideal casting properties; can be molded into large, thin-walled components at near net shape***
- ***Current usage and future increased usage impacted by high reactivity and susceptibility to corrosion (especially galvanic corrosion); relatively soft and susceptible to scratching; adhesion problems of coatings***

H-60 Transmission System Powertrain

All gearbox housings fabricated from Mg alloys

Number of H-60 helicopters in service:
Army: 1600
Navy: 350



U35-213 TRANSMISSION SYSTEM POWERTRAIN

68D4007

Current Methods for Providing Surface Protection to Magnesium Alloy Components

- *For OEMs such as Sikorsky, surface is hard anodized using the Dow 17 process followed by application of a phenolic resin; for non-mating surfaces, chromate epoxy polyamide primer followed by epoxy paint are applied; for mating surfaces, sealant compounds are used*
- *For repair depots, surface corrosion protection provided by AMS-M-3171 (formerly MIL-M-3171) followed by phenolic resin and primer/paint for non-mating surfaces and sealant for mating surfaces*
- *Dow 17 and AMS-M-3171 processes both involve use of sodium dichromate containing hexavalent chromium; operations will be severely affected if new OSHA Cr(VI) PEL is implemented*

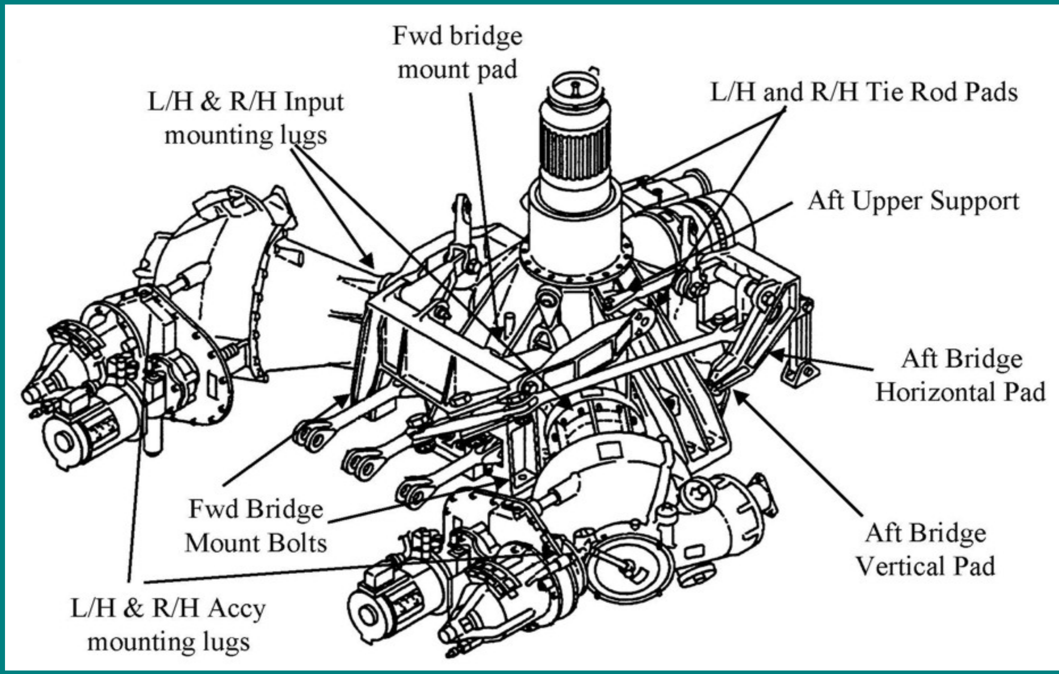
Magnesium Alloy Components on Joint Strike Fighter

- ***Four Mg components in power system***
  - ***Generator housing in Power and Thermal Management System***
  - ***Lube pump housing, oil tank, and engine start generator housing in Electrical Power System***
- ***Dow 17 would normally be used on these components but chromates are on JSF Restricted Materials List; therefore, JSF intends to investigate alternative surface protection processes***

Power and Thermal Management System magnesium alloy generator housing

Performance Problems With Current Surface Treatment Methods

- *Even with chromated surface treatments, Mg components suffer severe degradation in service*
- *Most corrosion occurs at mating pads, supports, and mounting lugs where dissimilar metal is in contact with Mg; damage is most likely to occur in those locations as well*



H-60 Main Transmission Housing showing areas most susceptible to corrosion

Corrosion on H-53 Tail Gearbox Housing

Requirements for Mg Alloy Components to Address ESOH Issues and Improve Performance

Requirements:

- *Alternative method that is ESOH benign for surface anodization of all surfaces to increase corrosion protection and scratch resistance*
- *ESOH-benign method for depositing aluminum coatings in critical areas to enhance corrosion protection and provide for restoration of severely corroded/damaged components; will enable restoration of components currently declared non-repairable*

Solution:

- *Plasma electrolytic oxidation (Tagnite or Keronite processes) for anodization is being qualified on components*
- *Supersonic particle deposition (SPD) of aluminum coatings on critical areas, combined with PEO, will provide TOTAL solution to problem*

Project Description

- ***Objective*: Demonstrate and qualify SPD aluminum alloy coatings as a cost-effective, ESOH-acceptable technology to provide surface protection and a repair/rebuild methodology for Mg alloy components on Army and Navy helicopters and advanced fixed-wing aircraft such as the Joint Strike Fighter**
- ***Technology Description*: SPD, also called cold spray, involves the introduction of a heated high-pressure gas such as He or N_2 together with 1- to 50-µm-diameter particles of a metal or alloy into a gun containing a nozzle designed such that the gas exits at supersonic velocities ranging from 400 to 1000 meters-per-second, considerably higher than those achieved by any thermal spray process**

  Because temperature of gas generally ranges from 200º to 400º C, no melting of particles takes place, plus there is no oxidation or decomposition of deposited particles

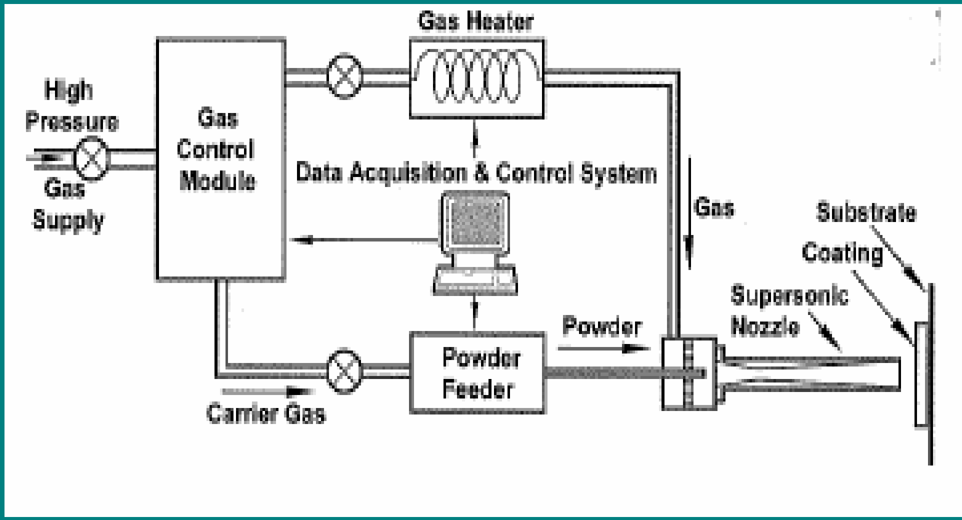
Description of SPD Process

Advantages of SPD Process:

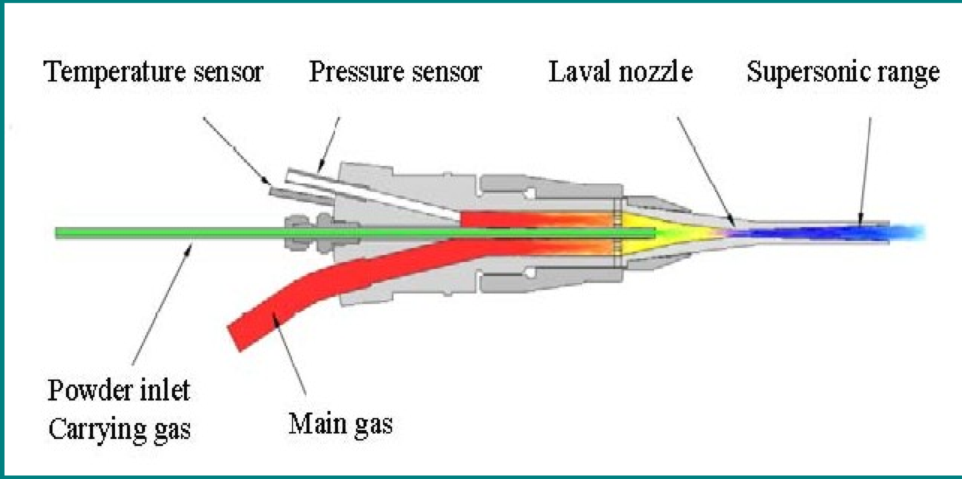
- *Extremely dense coatings with virtually no inclusions or cracks*
- *High deposition rates*
- *Uniform microstructure*
- *Impact of particles imparts compressive surface stress*
- *Low heat input prevents oxidation of Mg substrate*
- *Thickness ranges from 0.001” to > 0.050”*

Experimental and computational studies have led to modeling of the particle impact and bonding mechanisms

SPD similar to explosive bonding, leading to metallurgical bond (very important for Mg)

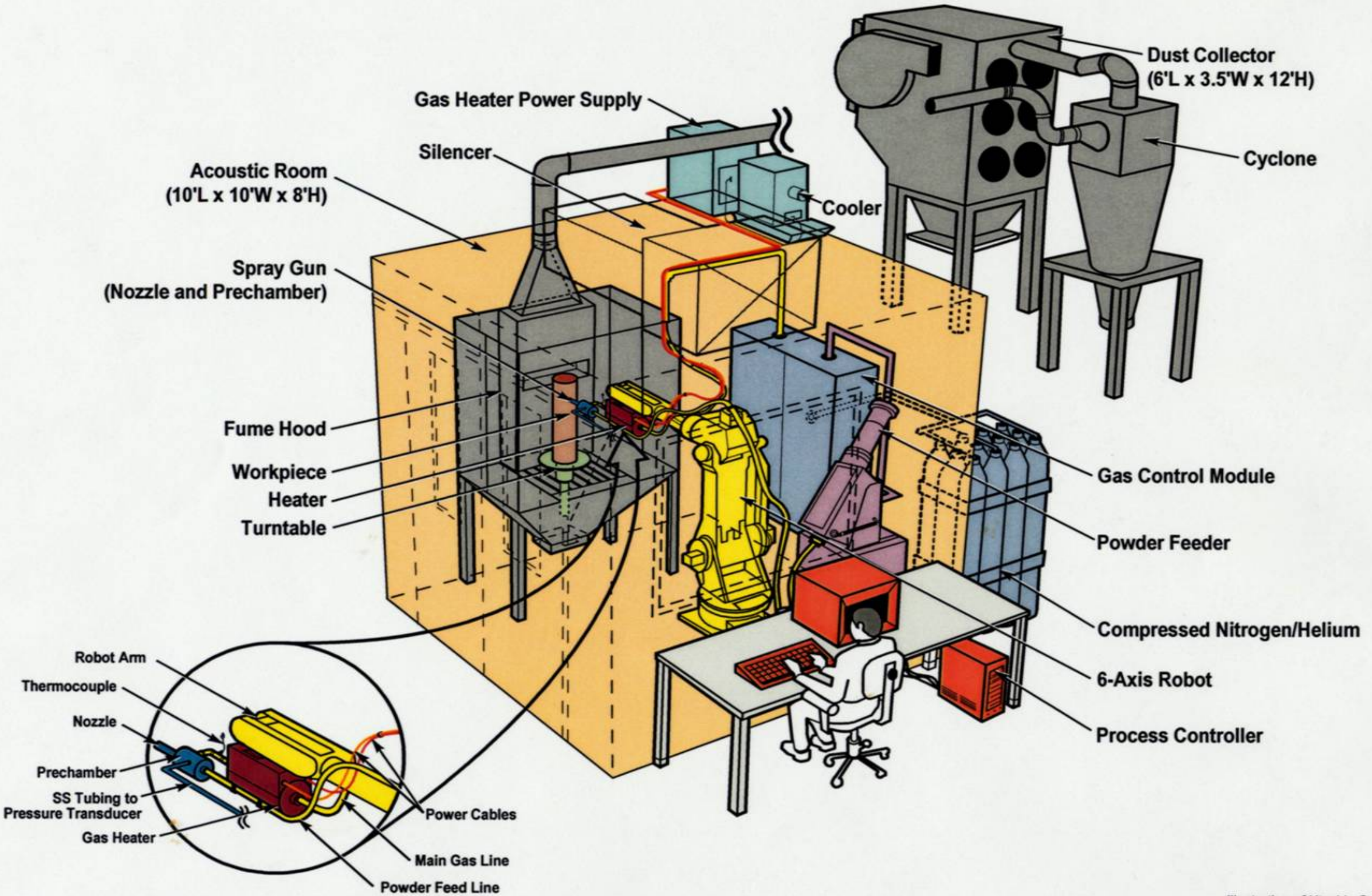


Simplified schematic of the SPD Process



Schematic of the SPD gun and nozzle

Schematic of Ktech Stationary SPD System Used for R&D and Demonstrations at ARL



Previous Work Related to SPD Deposition of Aluminum on Mg Alloys

- In 2001, Australian Defence Science and Technology Organization (DSTO) initiated a program to evaluate effectiveness of Ti and Al SPD coatings to mitigate corrosion of RAN Mg helicopter components; in 2002, DSTO published preliminary results showing excellent coating adhesion and salt fog corrosion resistance beyond 140 hours for Al
- In 2004, DSTO initiated collaboration with ARL to further evaluate Al alloy deposition on Mg
- In 2004, Sikorsky initiated a collaboration with ARL to conduct studies of Al deposition on Mg; ARL received Army funding to support project; adhesion of Al-12%Si coatings deposited onto Mg panels exceeded Sikorsky requirements
- AMRDEC Aviation Engineering Directorate (AED) Storage, Analysis, Failure Evaluation and Reclamation (SAFR) Program provided T55 compressor housing ($17,575) and H-60 main module housing ($28,732) to ARL for demonstration

Project Execution

Project divided into six separate tasks as follows:

- ***Task 1**: Acquisition of SPD system and installation into NADEP-Cherry Point; training of personnel; performing demonstration depositions*
- ***Task 2**: Selection of optimum Al alloy/composite coatings; initial coatings to be investigated include:*
  - *5056 Al: good corrosion resistance & Mg compatibility*
  - *Al-12Si: good corrosion resistance & mechanical properties*
  - *Al/Al_2O_3 (10-20%) composite: better deposition efficiency*

  Optimum coating determined through microstructure, adhesion, and limited electrochemical/B117 corrosion testing
- ***Task 3**: Demonstration Plan, including development and execution of Materials Joint Test Protocol (JTP)*

Project Execution

- ***<u>Task 3 (continued)</u>: Following types of tests anticipated to be required for JTP***
  - ***Electrochemical corrosion testing including anodic polarization and galvanic corrosion***
  - ***ASTM B117 neutral salt fog and G85, Annex 4, SO_2 salt fog tests on intact and scribed Al-coated Mg panels***
  - ***Crevice corrosion tests using Sikorsky protocol***
  - ***Field corrosion testing of coated panels on test racks on Navy aircraft carrier***
  - ***Fretting fatigue tests using UTRC equipment***
  - ***Impact and scratch-resistance testing***
- ***<u>Task 4</u>: Technology transition and insertion***
  - ***Establish procedures for coating deposition on candidate components***
  - ***Establish surface prep and post-deposition finishing procedures***

Project Execution

- ***Task 5**: Cost and environmental evaluations*
  - *ECAM analysis by CTC for application of SPD Al on all relevant components at NADEP-CP*
  - *Implementation assessment by Rowan Technology Group for full insertion of SPD technology at NADEP-CP and CCAD*
- ***Task 6**: Program Management*
  - *Submission of monthly financial and quarterly progress reports*
  - *Preparation and submission of Demonstration Plan (incl. JTP)*
  - *Preparing fact sheet and presentations at IPRs*
  - *Preparation and submission of C&P and Final Reports*

Expected DOD Benefit

- ***Proposed project differs from, for example, project to replace EHC plating with HVOF coatings in that the performance of EHC was considered acceptable but there were ESOH issues***
- ***In proposed project, performance of current multi-step process is unacceptable, leading to rejection of many Mg housings at a very high cost***
- ***Benefits of proposed project are derived from:***
  - ***Contributing to elimination of Dow 17 and AMS-M-3171 processes involving Cr(Vi), a high priority due to pending PEL***
  - ***Providing additional corrosion protection to critical areas on Mg housings, resulting in longer life, leading to fewer rejections during overhaul***
  - ***Ability to reclaim previously rejected housings***
  - ***Potential of using portable SPD units to provide repairs in field, thereby reducing requirements for replacement and return of damaged components to depot***

Project Sponsors

ESTCP

Army

Joint Strike Fighter Program

Navy ManTech Program

Total of ~ $3.5 million committed over three years

Army funding will generally support ARL's coating development work, portion of execution of Materials JTP, demonstration of coating application on Army components, and CCAD/AMCOM involvement in project

JSF funding will support DSTO (with sub to ARL) in coatings development and materials testing for F-35 gearbox housings

Navy ManTech funding will generally support Applied Research Lab at Penn State (ARL-PS) for coatings development, training of NADEP-CP personnel, and demonstrations of coating application on Navy components

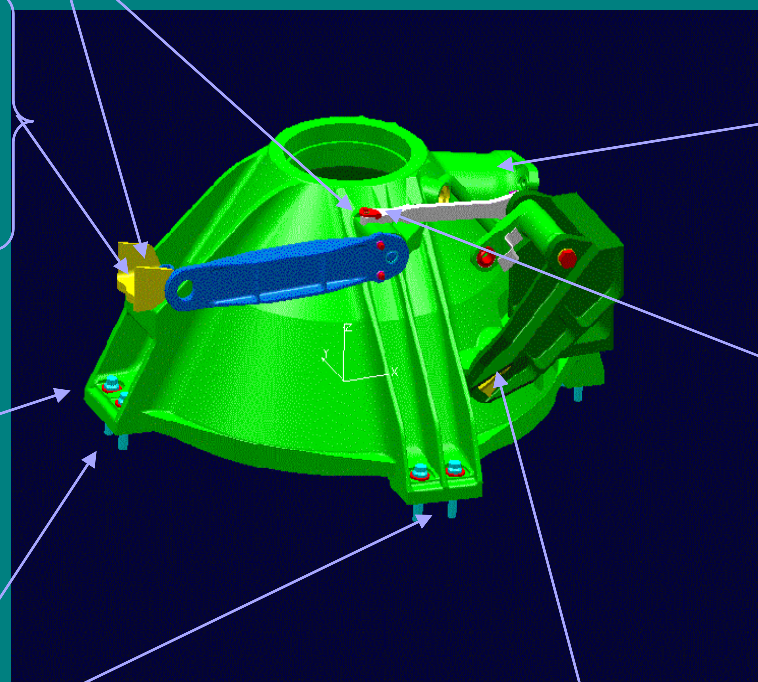
Overall Strategy for Improving Performance and Eliminating ESOH Issues on Mg Gearbox Housings as Recommended to NAVAIR by NADEP-CP

H-60 Main Gearbox Housing

•CA-1000 Non-hardening sealant (typical)

- Dowel Pin self-retention
- Jam-nut Eccentric Retain
- SPD Al alloy
- Drain "channel" on Pad
- Plated Liner & Pin

- Keronite Anodize



- SPD Al alloy
- Drain Contour on Pad
- Plated Liner & Pin

- Open Boss for Drain
- Al Plated Bushing (typical)

- SPD Al alloy

- Re-contour for "Unlimited Life" (from 4700 hrs.)

Summary

- *Project addresses class of components largely ignored in previous efforts to eliminate processes using Cr(VI)*
- *SPD of aluminum alloys part of overall solution to current problems associated with Cr(VI) usage and poor performance of Mg alloy components*
- *Project attributes:*
  - *Multi-service participation*
  - *OEM and contractor logistic support participation*
  - *Involvement of major new acquisition program (JSF)*
  - *International participation*
- *Successful completion of project should lead to substantially reduced life-cycle costs on rotary and fixed-wing aircraft*
- *Once implemented at depots, because of its flexibility, SPD technology will have many other potential applications*